# CEMENT
AND
# CEMENT MANUFACTURE

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## Rotary Kiln Heat Balance Notes.


By W. T. HOWE

(CHIEF CHEMIST, G. & T. EARLE LTD.)


IN previous articles (CEMENT AND CEMENT MANUFACTURE, May and July, 1933) the author gave a method of obtaining a fairly detailed heat balance when the required data are known, and the results naturally depend on the accuracy of this data. In many cases, however, the purpose in view, such as a comparison of one kiln or one factory with another, would, by the method outlined below, be served with an accuracy at least equal to that of the data by means of which a heat balance can be prepared in a few minutes by the use of a slide-rule and by substituting values in a few equations. The results will be accurate to the first decimal place within the usual range of temperatures, slurry moistures, etc. on a wet-process works.

This method is based on the fact that the heat values per pound of the various gases and clinker, as well as the weights, show only relatively small variations from a rectilinear relationship when plotted against the temperature or other factors involved. Fig. 1 gives the heat values for the different gases together with clinker in the kiln heat balance, and it will be seen that for the normal limits the variation from a straight line is practically negligible unless considerable accuracy is essential. These linear relationships have been found, and the derivation of the various equations required is indicated in the following. The references to tables are to those given in the articles already referred to.

(1) HEAT IN SLURRY MOISTURE.—Table I gave the weight of slurry moisture per 100 lb. of clinker. This table shows that the effect of variations in $CaCO_3$ are small, as a difference of 5 per cent. only alters the weight by 3 to 3½ per cent. Consequently only in exceptional cases need this factor be taken into account, and an average value of 77 per cent. $CaCO_3$ can be assumed for calculations of the heat loss. The weight can then be represented by 4.04 $(M - 14)$ lb. of water per 100 lb. of clinker, where $M$ = percentage of moisture in slurry. This

is only exact at the two points where the straight line cuts the curve, in this case at 35 and 40 per cent. moisture, but between these limits and somewhat beyond the deviation is negligible for our purposes, so that it can be assumed as being sufficiently correct between 33 and 42 per cent. slurry moisture, the extreme error being + 0.8 per cent. at these limits.

Dealing with the heat contained in 1 lb. of water vapour (Table II), in a similar manner it is found that between 200 deg. F. and 1,000 deg. F. the heat may be expressed very closely by

Heat contained in 1 lb. of water vapour at $T$ deg. F.

$$= 0.47\ (T + 2{,}190)\ \text{B.T.U.}$$

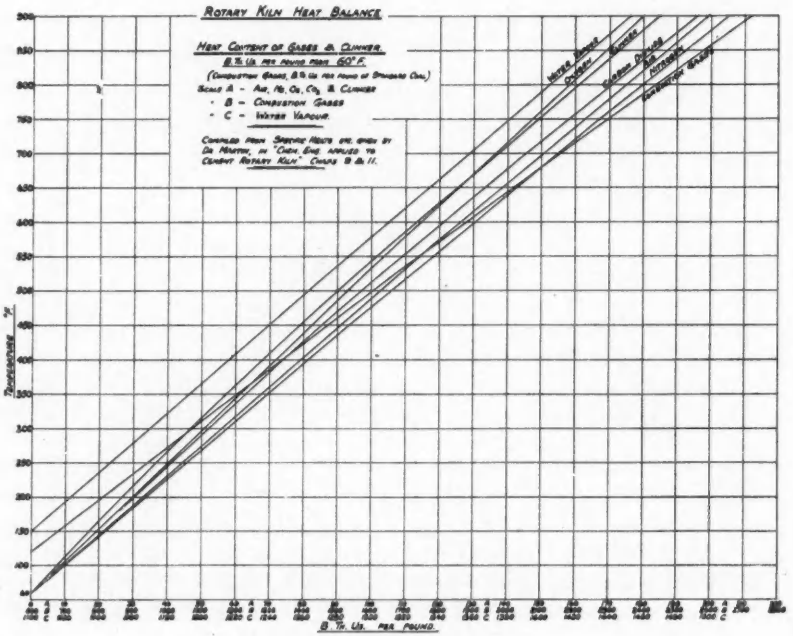
ROTARY KILN HEAT BALANCE
HEAT CONTENT OF GASES & CLINKER
B.Th. Us PER POUND FROM 60° F.
(COMBUSTION GASES, B.Th. Us PER POUND OF STANDARD COAL)
SCALE A - AIR, N2, O2, CO2 & CLINKER
" B - COMBUSTION GASES
" C - WATER VAPOUR.
COMPILED FROM SPECIFIC HEATS GIVEN BY DR. HEILIG, IN "CHEM. ENG. APPLIED TO CEMENT ROTARY KILN" CHAPS 9 & 11.
WATER VAPOUR
COMBUSTION GASES
CLINKER
AIR
INTERMEDIATE
EXTINCTION GASES
TEMPERATURE °F.
B.Th. Us PER POUND

**Fig. 1.**

This multiplied by the weight for 100 lb. of clinker and divided by 12,600 gives the percentage of standard coal represented by the water vapour evaporated from slurry moisture.

$$\frac{4.04\ (M - 14) \times 0.47\ (T + 2{,}190)}{12{,}600}$$

$$= 150.7 \times 10^{-6}\ (M - 14)\ (T + 2{,}190)\ \text{per cent. standard coal.}$$

A correction for variations in $CaCO_3$ may be applied if considered desirable by adding or subtracting 0.6 per cent. of this amount for each 1 per cent. of

$CaCO_3$ above or below 77 per cent. The following items have been calculated in a similar manner.

(2) HEAT REQUIRED FOR DECOMPOSITION OF CARBONATES.—Assuming an average value for $MgCO_3 = 1.5$ per cent., from Table III :

Heat required $= 0.139\ (L - 25)$ per cent. standard coal.

where $L$ = per cent. $CaCO_3$ in slurry.

(3) HEAT LOST IN $CO_2$ FROM RAW MATERIALS.—From Table IV, with the same allowance for $MgCO_3$,

Weight of $CO_2 = 1.032\ (L - 25)$ lb. per 100 lb. clinker.

From Table V, 1 lb. $CO_2$ at $T$ deg. F. contains $0.2425\ (T - 100)$ B.T.U.

$$\text{Heat required} = \frac{1.032\ (L - 25) \times 0.2425\ (T - 100)}{12{,}600}$$

$$= 19.85 \times 10^{-6}\ (L - 25)\ (T - 100) \text{ per cent. standard coal.}$$

(4) HEAT LOSSES IN COMBUSTION GASES.—From Table VI, where $N$ = standard coal consumption and $T$ deg. F. = exit gas temperature, the heat loss due to combustion gases is

$$218.4 \times 10^{-6}\ N(T + 85) \text{ per cent. standard coal.}$$

(5) HEAT LOSSES DUE TO EXCESS AIR.—For the usual values of oxygen in exit gases as found by Orsat analysis, the percentage of excess air

$$(E) = 5.8 \times \text{per cent. oxygen } (= C).$$

Consequently the weight of excess air $= 0.0992 \times 5.8\ CN$ lb. per 100 lb. of clinker (Tables VII and VIII). From Table IX, the heat per lb. of air $= 0.24\ (T - 70)$ B.T.U. Heat loss due to excess air

$$= \frac{0.0992 \times 5.8\ NC \times 0.24\ (T - 70)}{12{,}600}$$

$$= 11 \times 10^{-6}\ CN\ (T - 70) \text{ per cent. standard coal.}$$

(6) HEAT LOSSES DUE TO CO IN EXIT GASES (Table X).—This loss

$$= 0.0337\ b\ (N + 3) \text{ per cent. standard coal.}$$

(7) HEAT LOSS DUE TO COAL MOISTURE.—This loss

$$= 0.373 \times 10^{-6}\ m\ \frac{N}{F}\ (T + 2{,}190) \text{ per cent. standard coal.}$$

where $m$ = per cent. moisture in coal having standard coal factor $= F$.

(8) HEAT LOSS DUE TO CLINKER TEMPERATURE (Table XI).—

Where $t$ = clinker temperature leaving cooler, deg. F., the heat lost

$$= 1{,}650\ (t - 70) \times 10^{-6} \text{ per cent. standard coal.}$$

(9) LOSSES NOT ACCOUNTED FOR.—These losses (except radiation) may be included together and will be covered in normal cases by

$$67 \times 10^{-6}\ (T + 4{,}000) \text{ per cent. standard coal.}$$

The items on the credit side need no further reduction, except in the case of Nos. 2 and 3 to reduce B.T.U. to per cent. standard coal (divide by 12,600).

Examples of heat balances worked out by this and the original method follow. In columns *A* is the heat balance given as an example in the preceding article. In columns *B* the following changes in the data have been made in order to show the effect of rather extreme conditions: slurry moisture, 43.5 per cent.; $CaCO_3$, 74.5 per cent.; oxygen in exit gases, 4.2 per cent.; CO in exit gases, 0.5 per cent.; exit gas temperature, 870 deg. F.; clinker temperature, 620 deg. F.; standard coal, 32.3 per cent.

| | *A* | | *B* | |
|---|---|---|---|---|
| HEAT LOSS DUE TO | Original. | Simplified. | Original. | Simplified |
| Slurry moisture .. .. | 9.79 | 9.81 | 13.63 | 13.61 |
| Dissociation of carbonates .. | 7.26 | 7.27 | 6.87 | 6.88 |
| $CO_2$ in raw materials.. .. | 0.49 | 0.49 | 0.76 | 0.76 |
| Combustion gases .. .. | 3.50 | 3.50 | 6.75 | 6.73 |
| Excess air .. .. .. | 0.24 | 0.24 | 1.31 | 1.19 |
| CO .. .. .. .. | 0.23 | 0.23 | 0.59 | 0.60 |
| Coal moisture .. .. | 0.23 | 0.23 | 0.33 | 0.33 |
| Clinker.. .. .. .. | 0.26 | 0.26 | 0.94 | 0.91 |
| Miscellaneous .. .. .. | 0.23 | 0.31 | 0.27 | 0.33 |
| | 22.23 | 22.34 | 31.45 | 31.34 |
| Balance unaccounted for .. | 4.28 | 4.17 | 2.81 | 2.92 |
| Total .. .. .. | 26.51 | 26.51 | 34.26 | 34.26 |
| HEAT GAIN DUE TO | | | | |
| Coal consumed .. .. | 24.50 | 24.50 | 32.30 | 32.30 |
| Exothermic reaction .. .. | 1.43 | 1.43 | 1.43 | 1.43 |
| Organic matter .. .. | 0.58 | 0.58 | 0.53 | 0.53 |
| Total .. .. .. | 26.51 | 26.51 | 34.26 | 34.26 |

As the items on each side of the heat balance are now expressed as equations by their summation a general equation can be formed which will relate coal consumption with the variables, exit gas temperature, slurry moisture, calcium carbonate, excess air, clinker temperature, etc. Some of these have only a relatively small effect due to methods of control keeping them within definite limits, so that average values could be substituted in order to simplify the general equation and thus bring out better the effect of the principal factors, which are coal consumption, exit gas temperatures, slurry moisture, and radiation losses. The following equations have been evolved on these lines, by substituting the average values:

| | | | |
|---|---|---|---|
| Calcium carbonate .. | 77 per cent. | Clinker temperature .. | 250 deg. F. |
| Magnesium carbonate . | 1.5 per cent. | Oxygen in exit gases .. | 1.8 per cent. |
| Organic matter.. .. | 1 per cent. | CO in exit gases .. | 0.1 per cent. |
| Coal moisture .. .. | 8 per cent. | | |
| Standard coal factor .. | 0.9 | | |

$$N(4{,}030 - T = 0.624\,M(T + 2{,}190) + 3.6\,(1{,}250 - T) + 4{,}140\,R \quad .. \quad (1)$$

$$R = \frac{N(4{,}030 - T)}{4{,}140} - \frac{M(T + 2{,}190)}{6{,}640} - \frac{1{,}250 - T}{1{,}150} \quad .. \quad .. \quad (2)$$

$$N - R = \frac{N(T - 110)}{4{,}140} + \frac{M(T + 2{,}190)}{6{,}640} + \frac{1{,}250 - T}{1{,}150} \quad .. \quad .. \quad (3)$$

$$T = \frac{4{,}030(N - 1.03\,R) - 1{,}366\,(M + 3.3)}{N + 0.624\,(M - 5.8)} \quad .. \quad .. \quad .. \quad (4)$$

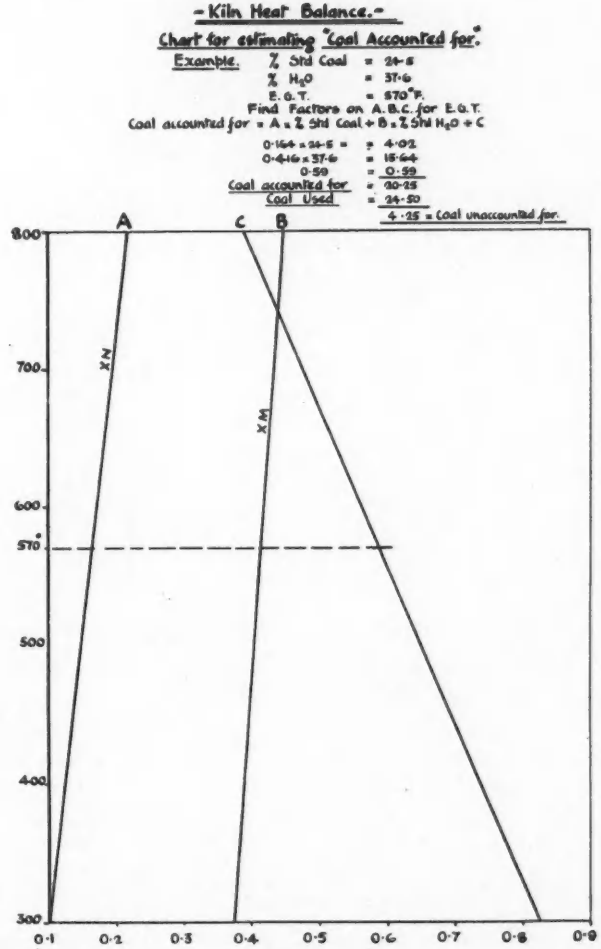


Fig. 2.

In these equations $N$ = per cent. standard coal, $M$ = per cent. slurry moisture, $T$ = exit gas temperature (deg. F.), $R$ = losses unaccounted for (mainly radiation losses).

From these equations any of the variables, such as coal, temperature or radiation losses, etc., may be calculated when the others are known, assuming that the kiln is being worked under the conditions mentioned. Considerable variations may occur in the minor variables without seriously upsetting the balance.

Probably for general purposes of comparison equation (3) is best as this will give the " coal accounted for," although to agree with the heat balance 2 per cent. should be added to allow for the heat value of exothermic reaction of clinker formation and the organic matter usually present in raw materials. Thus, applying it to the two examples,

$A$ gives 20.24 per cent. accounted for, and 4.26 per cent. unaccounted for.
$B$ ,, 28.02 ,, ,, ,, 4.28 ,, ,, ,,

Comparing with the heat balances, $A$ agrees very well, but $B$ shows a difference of $31.45 - 28.02 - 2.0 = 1.43$ per cent., allowing 2 per cent. for credit additional to coal used. This is explained by the divergencies from standard conditions in excess air, carbon monoxide, and clinker from cooler temperature. This is an illustration of the use which may be made of these equations ; if the normal coal accounted for, or alternatively, that not accounted for, is known, the use of these equations will often reveal that this figure has altered and thus call attention to a possible saving. It can be used in cases where full information is not available, and the results obtained would show whether special attention were required to be given to such points as gas analysis, kiln linings, pyrometer calibration, etc.

Fig. 2 will enable these values to be found readily. The example given shows its use. Factors $A$, $B$ and $C$ are found from the straight lines for the exit gas temperature. Then the addition of $A \times$ per cent. standard coal $+ B \times$ per cent. slurry moisture $+ C$ gives the " coal accounted for," and this deducted from the coal used gives " losses unaccounted for." It then becomes a matter for inquiry as to whether this figure is normal or not.

In Table I of this article equation (1) has been used to calculate the percentage of standard coal to clinker which would be used under normal conditions for various exit gas temperatures and slurry moistures. The value of $R$ (radiation losses, etc.) has been assumed at 3.5 per cent. of standard coal. It will be noticed that for each temperature the increase in standard coal is proportional to the increase in moisture. This can be seen by inspection of the equations, when $T$ and $R$ are constant.

Further light may be shed on the meaning of these relationships by differentiation. We can then obtain

$$(4{,}030 - T)dN = (N + 0.624\,M - 3.6)dT + 0.624(2{,}190 + T)dM + 4{,}140\,dR \quad (5)$$

Substituting the value of $N$ from equation (1) gives an alternative form

$$(4{,}030 - T)dN = \frac{3{,}880}{4{,}030 - T}(M + 1.07\,R - 2.6)\,dT + 0.624\,(2{,}190 + T)\,dM + 4{,}140\,dR \quad \ldots \quad \ldots \quad \ldots \quad (6)$$

It is probably nearly correct to say that the effect on radiation losses, etc., is relatively small when the coal used alters, i.e., these losses depend more on the kiln dimensions (surface) than on the output or coal burnt. Consequently the term containing $dR$ may be considered as negligible in the following treatment.

It was found in a mathematical investigation of the heat transfer from the results obtained from 24 kilns that a general equation could be obtained which represented with fair accuracy the relations between coal consumption and kiln dimensions, added internal surface, clinker output, and slurry moisture. It was found from this equation that in the cases considered, which covered considerable ranges of kiln dimensions, outputs, slurry moistures, and other factors, that the rate of increase of coal consumption for an increase in slurry moisture was almost constant, varying only from 0.77 to 0.83 per cent. increase in coal for 1 per cent. increase in moisture, and was almost independent of other factors.

Assuming this value to be correct, i.e.,

$$\frac{dN}{dM} = 0.8$$

this may be substituted in either equation (5) or (6), and if it is also assumed that $\frac{dR}{dN} = 0$ we can then obtain

$$\frac{dT}{dM} = \frac{(1{,}305 - T)\,(4{,}030 - T)}{3{,}800(M + 1.07\,R - 2.6)} \quad \ldots \quad \ldots \quad \ldots \quad \ldots \quad (7)$$

This equation gives the rate of increase of exit gas temperature for an increase in slurry moisture. It may appear strange that the temperature increases with the moisture, but this is the case if the coal increases with moisture at the rate assumed, i.e., 0.8 per cent. increase in coal consumption for 1 per cent. increase in slurry moisture (except when the temperature is above 1,305 deg. F.).

TABLE I.

STANDARD COAL AS PER CENT. OF CLINKER FOR VARYING EXIT GAS TEMPERATURE AND SLURRY MOISTURE.

| Exit gas temperature deg. F. | Per cent. Slurry Moisture. | | | | |
|---|---|---|---|---|---|
| | 34 | 36 | 38 | 40 | 42 |
| 200 | 18.0 | 18.8 | 19.6 | 20.4 | 21.1 |
| 300 | 18.9 | 19.8 | 20.7 | 21.5 | 22.3 |
| 400 | 20.0 | 20.9 | 21.8 | 22.7 | 23.5 |
| 500 | 21.1 | 22.0 | 22.9 | 23.8 | 24.7 |
| 600 | 22.2 | 23.2 | 24.2 | 25.2 | 26.2 |
| 700 | 23.4 | 24.4 | 25.5 | 26.6 | 27.7 |
| 800 | 24.6 | 25.7 | 26.9 | 28.0 | 29.1 |
| 900 | 26.0 | 27.2 | 28.4 | 29.7 | 31.0 |
| 1,000 | 27.4 | 28.7 | 30.0 | 31.3 | 32.7 |

It is possible that in certain kiln arrangements this relationship does not hold good, but general experience shows that it is of this order in the ordinary case. Table II is calculated from equation (7) and shows the increase in temperature due to an increase in slurry moisture of 1 per cent.

TABLE II.

RATE OF INCREASE IN EXIT GAS TEMPERATURE FOR INCREASE OF 1 PER CENT. OF SLURRY MOISTURE.

| Exit gas temperature deg. F. | Per cent. Slurry Moisture. | | |
|---|---|---|---|
| | 34 | 38 | 42 |
| 200 | 31 | 28 | 25 |
| 400 | 24 | 22 | 20 |
| 600 | 18 | 16 | 14 |
| 800 | 12 | 11 | 10 |
| 1,000 | 7 | 6 | 5 |

It is hoped that these notes, together with the previous articles, will assist those concerned with kiln control, and help them to make use of the data available. The writer wishes to acknowledge his indebtedness to the valuable advice and help so freely given by his chief, Mr. F. W. Davis, in the preparation of these articles.

## Canadian Specification for Portland Cement.

It is reported that the Committee on Portland Cement of the Canadian Engineering Standards Association has been considering suggestions for revisions to the present specification for Portland cement. These suggestions provided for an increase in the specified tensile strengths of mortar briquettes and the inclusion of provisions covering high early strength Portland cement. It has been decided, however, that it will not be necessary to make a revision at the present time, particularly as investigations are now being made with reference to compressive strength tests of cement to replace the present tensile tests. Experimental compression tests are being made with this object in view.

## Import Duties on Cement Materials.

The Import Duties Advisory Committee gives notice of applications for an increase in the import duty on raw gypsum stone (calcium sulphate), plaster of Paris, mineral white (ground gypsum), and calcium sulphate cements. Any representations which interested parties may desire to make in regard to these applications should be addressed in writing to the Secretary, Import Duties Advisory Committee, Caxton House (West Block), Tothill Street, Westminster, S.W.1, not later than September 25, 1933.

# Free Lime in Portland Cement.

By G. E. BESSEY*
OF THE BUILDING RESEARCH STATION.

MUCH consideration has been given, especially during the last few years, to the free lime content of Portland cements, both as a constituent of the clinker and as one of the hydration products. A number of workers have investigated methods of determination, and satisfactory methods are now available for determining the total free lime content. The present paper deals with the importance of discriminating between free calcium oxide and hydroxide in cements, and with the effect of these compounds on soundness.

## Methods of Determination.

Methods of determining free lime have been reviewed in a recent publication of the Building Research Station.[1] The glycerol method as described by Lerch and Bogue[2] was found to be the most satisfactory for determining the total free lime content of unhydrated hydraulic cements, and has been used in the present work.

Although of considerable importance, no distinction has been made in previous work between the free lime present as calcium oxide and as hydroxide. A simple method has now been developed for determining the calcium hydroxide content, so that when the total free lime content is also known, an estimate of the free calcium oxide content of a cement can be made. The method is of relatively low accuracy, but is adequate for many purposes. The basis is as follows.

Fresh cement contains a small proportion of water, combined either in calcium hydroxide or in hydrated cement compounds (including gypsum). On heating the cement, the water combined in the hydrated compounds other than calcium hydroxide is mainly lost over the range of temperature below 350 deg., whilst that combined as hydroxide is lost practically entirely between 350 deg. C. and 550 deg. C.[3] Further, in some other unpublished work carried out at the Building Research Station on the loss of water from set cements on heating, it has been found that the ratio of the loss at 550 deg. to that at 350 deg. C. due to the hydrated cement compounds present (excluding $Ca(OH)_2$), varies from 1.07 to 1.12 with a mean value of 1.09. Now loss at 350 deg. = loss from hydrated cement compounds ($x_1$), and loss at 550 deg. C. = loss from hydrated cement compounds ($x_2$) + loss from $Ca(OH)_2$. Hence, putting $x_2 = kx_1$, where k = 1.09, the $Ca(OH)_2$ content (expressed as CaO) = [loss at 550 deg. C. $- k$ (loss at 350 deg. C.)] $\times \frac{56}{18}$.

The value of $k$ is known only very approximately, especially since the relative amount of hydration of the silicates and aluminates is not known. This ratio has been determined, however, on both silicate and aluminate hydration products, and

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[1] B. Bakewell and G. E. Bessey, Building Research Special Rept. No. 17, 1931.
[2] Ind. Eng. Chem., 1926, 18, 739; *ibid.* (Anal.), 1930, 2, 296.
[3] G. E. Bessey, Building Research Tech. Paper No. 9, 1930.

is found to vary from about 1.07 to 1.14, a range similar to that found with the different hydrated cements.

Since $k$ can be known only roughly, the method could be useful only if the loss at 350 deg. C. is low.† This is the case in fresh cements, where it rarely amounts to more than 1.0 per cent. The error here due to inaccuracy in $k$ is therefore small, a divergence of 0.05 from the true value in $k$ causing a maximum error of 0.15 per cent. CaO.

The loss determinations are carried out by heating for thirty minutes in a small electric tube furnace held at the temperature required, as previously described.[3] As the process involves two determinations of loss, each of which may be taken as having an uncertainty amounting to $\pm 0.05$ per cent., the experimental error may be taken as $\pm 0.1 \times \frac{56}{18} = 0.3$ per cent. CaO. Allowing also for the approximations made for the losses due to other constituents, an overall uncertainty for the percentage of CaO as hydroxide amounting to not more than $\pm 0.5$ is possible, and the result can be taken as approximate to that degree only.

A large number of samples of Portland cements, taken mainly from commerce, have been tested, by these methods, for free calcium hydroxide and total free lime. The samples varied widely in character and composition and may be taken as representative of cements at present on the British market. The results of a number of these, together with results of other tests on the same samples, are given in Tables I and III and discussed in the following.

**Cause of Presence of Free Calcium Oxide in Cement.**

The presence of free calcium oxide in fresh Portland cements can be ascribed to various causes, such as an unsuitable composition of the raw mix or lack of homogeneity therein, insufficient burning of the clinker to permit combination of the lime to take place, or decomposition of lime compounds subsequent to burning with liberation of free CaO.

There are various formulæ which are used for proportioning raw mixes, and two recent ones which have met with a fairly general acceptance are those of Kühl[4] and of Guttmann and Gille.[5] From our present knowledge of the constitution of cement the formula of Guttmann and Gille seems preferable. These formulæ are as follows:

Kühl: lime modulus = (total CaO − CaO combined as $CaSO_4$) ÷ ($2.8SiO_2 + 1.1Al_2O_3 + 0.7Fe_2O_3$) (assuming $3CaO,SiO_2 + 2CaO,Al_2O_3 + 2CaO,Fe_2O_3$).

Guttmann and Gille: lime modulus = (total CaO − CaO combined as $CaSO_4$) ÷ ($2.8SiO_2 + 1.65Al_2O_3 + 0.35Fe_2O_3$) (assuming $3CaO,SiO_2 + 3CaO,Al_2O_3 + 4CaO,Al_2O_3,Fe_2O_3$).

† For this reason the method cannot be applied satisfactorily to hydrated cements, in which the loss at 350 deg. C. is large. For such materials a calorimetric method has previously been developed (Bessey, *loc. cit.*) depending on a measurement of the heat of hydration of the calcium oxide produced by heating the set cement to 550 deg. C. Although apparently applicable to fresh cements this calorimetric method has not in practice proved satisfactory with such materials containing only small amounts of calcium hydroxide relative to the total cement content.

[4] Zement, 1929, 18, 833. [5] *Ibid.*, 912.

An examination of the data in Table I., in which samples are arranged in order of total free lime content, shows that there is little relation between the closeness with which these moduli approach unity (the maximum value in which all lime can combine with the other components) and either the free CaO or total free lime content.

TABLE I.

FREE LIME AND "LIME MODULI" OF CEMENTS.

| No. of cement sample. | Total free lime. Per cent. | Free CaO. Per cent. | Lime Modulus K. | Lime Modulus G. & G. |
|---|---|---|---|---|
| 1 | 0.4 | 0 | 0.86 | 0.84 |
| 2 | 0.7 | 0 | 0.93 | 0.90 |
| 3 | 0.7 | 0 | 0.98 | 0.94 |
| 4 | 0.8 | 0 | 0.98 | 0.92 |
| 5 | 1.0 | 0 | 0.97 | 0.93 |
| 6 | 1.2 | 0 | 0.90 | 0.88 |
| 7 | 1.4 | 0 | 0.90 | 0.87 |
| 8 | 1.7 | 0 | 0.94 | 0.92 |
| 9 | 1.8 | 0.5 | 0.91 | 0.88 |
| 10 | 2.0 | 0 | 0.97 | 0.92 |
| 11 | 2.0 | 0 | 0.97 | 0.92 |
| 12 | 2.2 | 1.0 | 1.01 | 0.96 |
| 13 | 2.2 | 1.0 | 0.95 | 0.93 |
| 14 | 2.3 | 1.0 | 0.91 | 0.87 |
| 15 | 2.4 | 1.5 | 0.95 | 0.92 |
| 16 | 2.6 | 0 | 0.94 | 0.90 |
| 17 | 2.9 | 1.5 | 0.95 | 0.91 |
| 18 | 3.5 | 0.5 | 0.97 | 0.93 |
| 19 | 3.6 | 1.0 | 0.92 | 0.89 |
| 20 | 3.7 | 1.5 | 0.97 | 0.94 |
| 21 | 3.9 | 2.5 | 0.95 | 0.91 |
| 22 | 4.2 | 1.0 | 1.04 | 0.99 |
| 23 | 4.6 | 0 | 0.97 | 0.93 |
| 24 | 5.2 | 1.5 | 0.90 | 0.87 |

While these formulæ cannot be regarded as giving a complete representation of the compounds in Portland cement, it does appears that the presence of free CaO in cement clinker is not due primarily to the mean composition of the raw mix. Insufficient mixing, or lack of fineness of grinding of the raw materials, may cause the combination to be incomplete, but it appears more probable that the presence of free lime in the clinker must be ascribed in most cases to some degree of underburning.

The possibility of free CaO being formed in appreciable amount during the cooling of the clinker, or subsequently, due to decomposition of the tricalcium silicate must be considered in light of the recent work of Carlson[6] and others. This decomposition has been observed during ignition of cements at temperatures of 700 deg. C. to 1,300 deg. C., and it might therefore occur to some extent during the cooling of the cement clinker. An examination of the results so far obtained indicates that the amount of such decomposition is likely to be negligible. The

[6] Rock Products, 1931, 34, No. 25, 52. Bur. Stand. J. Res., 1931, 7, 893.

rate of decomposition is very low even at the optimum temperature (about 1,150 deg. C.) and the clinker is not held long in the temperature range over which the rate is appreciable (900—1,250 deg. C.). However, the reaction has been insufficiently studied for it to be stated that it can be entirely neglected in this connection, and the relative effect of slow cooling and quenching of clinker on the free lime content needs some examination.

In this connection, it may be stated that no indication was found, in two samples, with total free lime contents of 2.0 per cent. and 4.0 per cent. respectively, tested during the present investigation, of any real increase in total free lime content after sealed storage for one year at 20 deg. C.

### Presence of Free Calcium Hydroxide in Cement.

The results given in Table I show that a large proportion of the total free lime in fresh cements is present as calcium hydroxide. Theoretically this calcium hydroxide may arise either from hydration of calcium oxide present in the clinker or from hydration of cement compounds. The water required for these hydration processes may be derived from atmospheric moisture taken up during storage of the clinker prior to grinding, from water sprayed on to the clinker to assist in cooling, or from the moisture and water of hydration of the gypsum added during grinding. The temperature reached by a cement during grinding in large mills is above that at which gypsum ($CaSO_4,2H_2O$) is dehydrated to form the hemihydrate ($CaSO_4,0.5H_2O$), but well below that at which calcium hydroxide is decomposed. Schachtschabel[7] has recently observed that this dehydration does occur, and it is well known that gypsum can hydrate calcium oxide in grinding.

A few tests have been carried out to show whether hydration of cement during grinding can occur. Two cement clinkers were ground with gypsum in a small ball mill in which the rise of temperature is not very great, and in which therefore only free water and a small part of the combined water in the gypsum should

TABLE II.

| Clinker No. | Method of treatment. | Free $Ca(OH)_2$ Per cent. CaO. | Free $Ca(OH)_2$. + CaO, Per cent. CaO. | Free CaO (by diff.) Per cent. CaO. |
|---|---|---|---|---|
| 1 | Ground alone in small ball mill .. .. | 0.4 | 0.4 | — |
| | Ground with 5 per cent. gypsum in small ball mill .. .. .. .. .. | 0.6 | 0.6 | — |
| | Previously ground clinker heated with 5 per cent. gypsum in loosely closed vessel for 1 hour at 150 deg. C. .. .. .. | 0.6 | 0.7 | 0.1 |
| 2 | Ground alone in small ball mill .. .. | 1.1 | 4.6 | 3.5 |
| | Ground with 5 per cent. gypsum in small ball mill .. .. .. .. .. | 2.2 | 4.1 | 1.9 |
| | Previously ground clinker heated with 5 per cent. gypsum in loosely closed vessel for 1 hour at 150 deg. C. .. .. .. | 2.6 | 4.3 | 1.7 |

[7] Zement, 1933, 22. 45.

be available for hydration of the cement. The ground clinkers were also mixed with gypsum which had been ground separately and the mix was heated to 150 deg. C. under conditions such that little loss of water from the system could occur. The results in Table II. show no real change in total free lime content with either clinker, but with the clinker of high initial free lime content there is an appreciable increase in the calcium hydroxide content at the expense of the calcium oxide content. It is inferred from these results that hydration of free lime occurs on grinding, but little hydration of the cement compounds such as to liberate additional free calcium hydroxide. This conclusion is supported by analyses of clinkers taken while hot from the coolers of cement kilns. The free lime contents, all present as CaO, varied from 0.3 per cent. to 4.6 per cent., which is of the same order as the range found for total free lime in ground cements as marketed. It appears therefore that most of the total free lime content found in ground cements is present in the clinker as it comes from the kiln ; it is present originally as calcium oxide, but during storage and grinding of the clinker much of it becomes hydrated to form the hydroxide.

The formation of calcium hydroxide may also proceed to some extent from aeration of the fresh cement, but under modern conditions of storage and packing of cements such effects are likely to be small. Most of the cements used in the present investigation were obtained directly from the manufacturers' works, and no change due to aeration subsequent to packing could have occurred.

**Free Lime and Unsoundness in Cements.**

The methods more commonly used for testing the soundness of cements are the Le Chatelier test, the steamed and cold pats, and the cold plunge tests. In the cold plunge test the pat is immersed in water immediately after making, whilst in the cold pat test it is kept up to twenty-four hours in moist air before immersion. The Le Chatelier test is the most useful, since it gives a quantitative measure of the unsoundness ; the pat tests give only qualitative results, and the cold plunge test is, as is shown by the results given in the following, of little or no value.

Unsoundness in cements has long been attributed to the presence of free lime. The total free lime contents of the cements shown in Table III range from 0.4 to 5.1 per cent. On the basis of limits which have been given for free lime contents in previous work, unsoundness might be expected in a considerable number of these cements. Lerch,[8] in an investigation on the cause of unsoundness in Portland cement, found it was due entirely to the presence of free lime, and that the limit above which unsoundness might be observed by the steamed pat test varied in different cements from 1 to 3 per cent. These limits were suggested mainly on the basis of results with laboratory cements. The commercial cements examined had almost all very high or low values of free lime content. Haegermann[9] gives 1 to 2 per cent. for the limit in the boiling pat test and up to 4 per cent. for the cold pat, using freshly prepared laboratory samples. Koyanagi[10]

[8] Concrete, 1929, 35, 109, 115.
[9] Zement, 1930, 19, 982.
[10] Rock Products, 1931, 34, No. 7, 74.

found similar limits, whilst Goffian ud Mussgnug[11] found freshly ground clinker with up to 2 per cent. of free lime passes the soundness tests satisfactorily.

Soundness tests (steamed pat, cold plunge, and Le Chatelier) have been carried out on the samples of cement given in Table III, and the cold plunge and Le Chatelier results are shown. The samples in this table are numbered to correspond with Table I, but are here arranged in order of the Le Chatelier expansion. The hot pat gave no unsoundness in any case except No. 27. All the samples tested would pass standard specification tests for soundness with the exception of Nos. 26 and 27, which were not taken from commerce but were drawn from experimental batches. Samples are shown in the table as slightly unsound in the cold

TABLE III.

FREE LIME AND UNSOUNDNESS IN COMMERCIAL CEMENTS.

| Sample No. | Total free lime, CaO Per cent. | Free calcium hydroxide, CaO Per cent. | Free calcium oxide, CaO Per cent.* | Le Chatelier expansion, mm. | Cold plunge test. | Fineness flour, Per cent. |
|---|---|---|---|---|---|---|
| 1 | 0.4 | 0.7 | 0 | 0 | Sound | Not Tested |
| 3 | 0.7 | 0.9 | 0 | 0 | Slightly unsound | 61 |
| 16 | 2.6 | 2.6 | 0 | 0 | Sound | 71 |
| 17 | 2.9 | 1.4 | 1.5 | 0 | Slightly unsound | 74 |
| 8 | 1.7 | 1.7 | 0 | 0.5 | Sound | Not tested |
| 9 | 1.8 | 1.2 | 0.5 | 0.5 | Sound | 66 |
| 18 | 3.5 | 2.9 | 0.5 | 0.5 | Sound | 66 |
| 20 | 3.7 | 2.3 | 1.5 | 0.5 | Sound | 70 |
| 2 | 0.7 | 0.9 | 0 | 1.0 | Sound | 59 |
| 5 | 1.0 | 1.6 | 0 | 1.0 | Sound | 65 |
| 6 | 1.2 | 1.1 | 0 | 1.0 | Slightly unsound | 74 |
| 11 | 2.0 | 1.9 | 0 | 1.0 | Sound | 58 |
| 23 | 4.6 | 4.2 | 0.5 | 1.0 | Sound | 89 |
| 15 | 2.4 | 1.8 | 0.5 | 1.0 | Sound | 61 |
| 10 | 2.0 | 0.8 | 1.0 | 1.0 | Sound | 65 |
| 12 | 2.2 | 1.4 | 1.0 | 1.0 | Sound | 72 |
| 13 | 2.2 | 1.4 | 1.0 | 1.0 | Sound | 65 |
| 14 | 2.3 | 1.5 | 1.0 | 1.0 | Sound | 65 |
| 4 | 0.8 | 0.8 | 0 | 1.5 | Sound | 51 |
| 7 | 1.4 | 1.2 | 0 | 1.5 | Sound | 62 |
| 22 | 4.2 | 3.4 | 1.0 | 2.0 | Slightly unsound | 71 |
| 24 | 5.2 | 3.8 | 1.5 | 2.0 | Slightly unsound | 78 |
| 25 | 3.4 | 1.6 | 2.0 | 3.0 | Slightly unsound | 73 |
| 21 | 3.9 | 1.6 | 2.5 | 4.0 | Sound | 73 |
| 26 | 4.9 | 1.4 | 3.5 | 5.0 | Not tested | Not tested |
| 27 | 5.1 | 1.7 | 3.5 | 53.0† | Unsound | Not tested |

* To nearest 0.5 per cent.
† Unsound also with steam pat tests.

plunge test when slight cracks or lifting at the edges were observed. As will be shown later, this test is useless.

[11] Zement, 1932, 21, 145, 178.

It is apparent from an examination of these results that a high total free lime content is not in itself necessarily an indication of unsoundness. In the Le Chatelier test, tendencies towards unsoundness (i.e., expansions greater than 2 mm.) are shown by Nos. 21, 25, 26 and 27. Each of these has a total free lime content greater than 3.0 per cent., but Nos. 18, 20, 22, 23 and 24, which are sound in this test, have similar free lime contents.

Comparison of these results in the Le Chatelier test with the free CaO contents shows, however, a much closer agreement with the limits found for freshly-prepared cements by other workers. Only four cements have free CaO contents of 2.0 per cent. or over; they are the same cements (Nos. 21, 25, 26, 27) as have Le Chatelier expansions greater than 2.0 mm.

The fineness of the cement has been considered to have an influence on results of soundness tests. Davis,[12,13] found that cements with small expansions of 2 to 4 mm. in the Le Chatelier test gave expansions of 20 to 40 mm. when the coarse residue on the 180-mesh sieve, and the "grit" passing the 180-mesh sieve but retained in elutriating, were tested; he concludes that the "flour," which is present in large proportion in the cements, prevents a large expansion due to the grit and coarse material. When the cement is inherently unsound through the presence of free calcium oxide this may be anticipated, since the free lime (CaO) in the fine flour probably hydrates more rapidly and the expansion occurs before the cement sets; in the coarser material, however, penetration of the water is necessarily slower, and hydration of the free lime occurs subsequent to setting, with resultant expansion and unsoundness. When a cement is not inherently unsound, however, there seems no reason to anticipate expansion in any fraction of the sample.

One cement has been tested to show whether this is the case. The sample tested was a rapid-hardening Portland cement having a total free lime content of 1.6 per cent. and a free CaO content less than 0.5 per cent. It was separated into three fractions, (1) residue on British Standard 170-mesh sieve, (2) grit passing 170-mesh sieve but left as a residue on elutriation, (3) flour elutriated in a standard elutriator.* The results of soundness tests on these fractions and on the original cement are shown in Table IV. There is no real difference in the expansion with the original cement and with any of the fractions, thus confirming the suggestion given. It will be noted also that on the cold plunge test the flour fraction of this cement appeared to be unsound. This is also shown by the data of Table III, where a number of cements appear unsound on the cold pat, but are sound by all other tests. Examination of the data suggests that this spurious appearance of unsoundness on the cold pat test is more prevalent in the cements of higher flour content. In actual effect finer grinding must reduce, and not

[12] Prox. Inst. Civ. Eng., 1908–1909, 175, Part I., 802.

[13] Cement, 1932, 5, 72.

* Flour contents given in the present paper were obtained with the standard air elutriator described by Davis [13].

increase, any tendencies for a cement with a given free lime content to show true unsoundness, although it may lead to this spurious unsoundness in the cold plunge test since the free lime can hydrate more readily before the cement sets.

TABLE IV.

SOUNDNESS OF PARTICLE SIZE FRACTIONS OF CEMENT.

| | Original cement | Residue on 170-mesh | Fine grit | Flour |
|---|---|---|---|---|
| Fraction of total cement per cent. .. .. .. | 100 | 2.2 | 24.0 | 73.8 |
| Le Chatelier expansion .. | 1.5 mm. | 1.0 mm. | 1.0 mm. | 0.5 mm. |
| Hot pat .. .. .. | Sound | Sound | Sound | Sound |
| Cold plunge .. .. .. | Sound | Sound | Sound | Unsound |

Only one cement (No. 27) has a very large expansion in the Le Chatelier test. Whilst this cement is in agreement with the general rule, in that it has the highest free CaO content (3.5 per cent.), it is remarkable that the expansion should be so markedly different from No. 26 which has a similar free CaO content. It must be inferred from these results that, although unsoundness is associated with the presence of much free CaO, the degree of unsoundness is not necessarily given by the amount thereof, other factors, amongst which is undoubtedly the effect of fineness on the availability of the free CaO in the cement, having some influence.

## Conclusions.

Emphasis has been laid on the importance of distinguishing between the free calcium oxide and hydroxide in considering the free lime contents of fresh cements. The proportion of the free lime present as hydroxide in commercial cements, as measured by a method involving determination of loss on ignition at two different temperatures, is high.

The total free lime present in commercial cements is due mainly to burning being insufficient for the mix used. There is no general relation between the degree of lime saturation of the cements and their free lime content, underburning being nearly as prevalent in low-lime as in high-lime cements. The free hydroxide portion may be formed either by spraying or exposure of clinker, by reaction with the water from the gypsum during grinding, or during storage of the ground cement.

It has been stated by various workers that unsoundness is due to free lime, and limits for free lime content have been suggested with no differentiation between the oxide and hydroxide. The results of free lime determinations and soundness tests on a number of commercial cements in the present work show that total free lime cannot be taken as a criterion of soundness, but that where free calcium oxide is present in amounts greater than about 2 per cent. unsoundness occurs. In cements as marketed the greater part of the free lime is usually present in the hydrated form.

# INTERNATIONAL DICTIONARY OF CEMENT.

ARRANGED BY DR. C. R. PLATZMANN, WITH COLLABORATORS IN ENGLAND, FRANCE, AND SPAIN.

(*Continued.*)

| FRENCH. | ENGLISH. | GERMAN. | SPANISH. |
|---|---|---|---|
| | | L | |
| laboratoire de cimenterie | cement testing laboratory | Zementprüflaboratorium | laboratorio de ensayo de cemento |
| laitier | slag | Schlacke | escoria |
| laitier de haut fourneau | blast-furnace slag | Hochofenschlacke | escoria de altos hornos |
| large, largeur | wide | breit | ancho |
| levier | hand lever | Handhebel | pabanca de mano |
| limite de charge | load limit | Belastungsgrenze | límite de carga |
| limite d'élasticité | yield point | Elastizitätsgrenze | límite de elasticidad |
| limiteur de course | trip gear | Ausklinkvorrichtung | mecanismo de desenclavamiento |
| liqueur ; solution | solution | Lösung | solución |
| liquide | liquid | Flüssigkeit | líquido |
| locomotive | locomotive | Lokomotive | locomotora |
| loupe | lens | Lupe, Linse | lente |
| lubrifiant | lubricant | Schmierfett | lubricante |
| lubrifier | lubricate, to | schmieren | engrasar |
| | | M | |
| machine à empaqueter, ensacheuse | packing machine | Packmaschine | máquina envasadora |
| machine à essayer | testing machine | Prüfmaschine | aparato de ensayo |
| machine à equicourant | uniflow steam engine | Gleichstromdampfmaschine | máquina de vapor de simple expansión |
| machine à vapeur | steam engine | Dampfmaschine | máquina de vapor |
| machine à vapeur compound à condensation | compound condensing steam engine | Verbunddampfmaschine m. Kondensation | máquina compound de vapor con condensación |
| machine d'essai de résistance à la compression | compression testing machine | Druckfestigkeitsprüfmaschine | máquina para el ensayo de la resistencia a la compresión |
| machine d'essai au choc | impact testing machine | Schlagprobemaschine | máquina de ensayo al choque |
| machinerie d'empaquetage | packing machinery | Packmaschinerie | maquinaria de envasado |
| maçonnerie | brickwork | Ziegelmauerwerk | cámara de ladrillo |
| maille | mesh | Masche | malla |
| malaxeur à mortier | mortar mixing machine | Mörtelmischmaschine | mezcladora de mortero |
| manille | manilla | Manilahanf | abacá |
| manutention pneumatique | pneumatic conveying plant | Pneumatische Förderanlage | instalación de transporte neumático |
| marne | marl | Mergel | marga |
| matière première | raw material | Rohmaterial | materia primera |
| matière volatile | volatile matter | flüchtige Substanz | material volatil |
| mélangeur à boues | slurry mixer | Schlammischer | mezclador de pasta |
| mètre | meter | Meter | metro |
| minerai | ore | Erz | mineral |
| mise à la terre | earthing | Erdung | toma de tierra |
| mise en sacs à la main | hand filling | Abfüllen, von Hand | envasado a mano |
| module de finesse | fineness modulus | Mahlfeinheitsmodul | módulo de finura |
| module de la chaux | lime modulus | Kalkmodul | módulo cálcico |
| moteur à bagues | slip ring motor | Schleifringmotor | motor de anillos rozantes |
| moteur à cage d'écureuil | squirrel-cage motor | Kurzschlussmotor | motor de jaula de ardilla |

| FRENCH. | ENGLISH. | GERMAN. | SPANISH. |
|---|---|---|---|
| moulage | casting | Gehäuse | pieza de fundición |
| mouler | mould, to | formen | moldear |
| moulin broyeur à trois chambres | three chamber mill | Dreikammermühle | molino de tres cámaras |
| mouture du clinker | clinker grinding | Klinkermahlung | molturación del clinker |
| moyen | average | Durchschnitt, Mittel | promedio |
| | | N | |
| nettoyer | clean, to | reinigen | limpiar |
| niveau | level | Niveau | nivel |
| nomenclatures | standard specifications | Normen | normas |
| | | O | |
| orifice | opening | Oeffnung | abertura |
| ossature, échafaudage | gantry | Gangbrücke | conducto de proteccion |
| outil | tool | Gerät, Werkzeug | herramienta |
| outil tranchant | cutting tool | Werkzeugschneide | herramienta de filo |
| ouverture | hole | Loch, Oeffnung | agujero |
| oxyde d'aluminium hydraté | hydrous oxide of aluminium | Aluminiumhydroxyd | óxido de aluminio hidratado |
| oxyde de carbone | carbon monoxide | Kohlenoxyd | protóxido de carbono |
| oxygène | oxygen | Sauerstoff | oxígeno |
| | | P | |
| palier à rouleaux | roller bearing | Walzlager, Laufringlager | soporte de rodillos |
| palier lisse | sleeve bearing / plain bearing | Muffenlager / Gleitlager | cojinete de manguito / cojinete ordinario |
| pâte, boue | slurry | Schlamm | pasta |
| perceuse | drilling machine | Bohrmaschine | máquina perforadora |
| perforatrice | rock drill | Gesteinsbohrer | perforadora o barrenadora para roca |
| perforatrice à air comprimé | compressed air drill | Pressluftbohrung | perforador de aire comprimido |
| perforatrice à percussion fonctionnant à l'air comprimé | jackhammer air drill | Luftbohrhammer | barrena montada en martillos de aire comprimido |
| perforatrice à percussion à air comprimé | compressed air hammer drill | Druckluftbohrhammer | martillo perforador neumático |
| perforer | perforate, to | durchlochen | perforar |
| perméabilité | permeability | Durchlässigkeit | permeabilidad |
| perte au feu | loss on ignition | Glühverlust | pérdida al fuego |
| perte de poids | loss of weight | Gewichtsverlust | pérdida de peso |
| pesanteur | gravity | Schwerkraft, Gewicht | peso |
| peser (machine à) | weigher | Waage | pesador, poidómetro |
| photomicrographie | photomicrograph | Mikroaufnahme | microfotografía |
| pierre ponce | pumice | Bimsstein | piedra pómez |
| pilier | pier | Pfeiler | pilar |
| piston | piston | Stempel Kolben | émbolo |
| piston plongeur | plunger | Tauchstab, Plunger | émbolo zambullidor |
| plaque tournante | turntable | Drehscheibe | plataforma rotatoria |
| plateau d'alimentation | table feed | Telleraufgabe | mesa de alimentación |
| plate-forme de chauffage | burner's platform | Brennplattform | plataforma del calcinador |
| plâtre de Paris | plaster of Paris | Stuckgips | yeso de Paris |
| poids | weight | Gewicht | peso |
| poids par litre | weight per litre | Litergewicht | peso por litro |
| poids spécifique | specific gravity | spezifisches Gewicht | peso específico |
| point de fusion | point of fusion | Schmelzpunkt | punto de fusión |
| point de transformation | transition point | Umwandlungspunkt | punto de transición |

*(To be continued.)*

## Book Review.

THE CHEMISTRY AND PHYSICS OF CLAYS AND OTHER CERAMIC MATERIALS. By ALFRED B. SEARLE. (Second Edition. Pp. 738 + xvi. London: Ernest Benn, Ltd. Price 55s. net.)

ALTHOUGH the application of chemistry and physics to the clay-working industries is comparatively recent, the scope for scientific work is apparently so great that it is said that the issue of articles and books on the subject exceeds five thousand a year. This flood of literature calls for a summary that will enable those interested to keep up to date in their knowledge, and the present volume should fill this need. The author has attempted more than a mere record of recent information, and has provided both a text book on the theoretical aspects of the ceramic industries —which will be useful to students making their first acquaintance with the subject —and a reference book for those requiring occasional information on clays, bricks, and allied materials. In many of its pages the book is elementary, and admirably clear definitions are given of the fundamental properties of matter. Subjects such as temperature, hardness, gels, the phenomenon of wetting, chemical constitution, porosity, etc., are dealt with in a way that should be understood by the untrained reader, although it is not to be expected that the same reader could grasp the more advanced treatment that is given, for example, to the phase rule which in its turn will appeal to the trained student. The book concentrates on the theoretical side of its subject, but is necessarily compelled to deal to some extent with the manufacture of bricks and pottery and the relation between the physical and chemical properties of raw and burnt clays and success or failure of manufactured articles.

The particular interest of the volume to cement manufacturers is to be found in the description of tests of refractory materials for spalling, resistance to corrosion, and fluxing, and in the discussions of the properties of clay and the structure of bricks likely to provide successful results in these directions. As already mentioned the book also has a considerable value for reference purposes.

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# Mechanical Air Separation.

In view of the successful installation of " Raymond " mechanical air separators in cement works in the United States, the following description of this apparatus will be of interest. This separator may be installed in conjunction with almost all types of mills, such as hammer, tube, roller, ball, attrition, beater, etc. When grinding products such as clay, cement clinker, limestone, phosphate rock, gypsum, silica, felspar, etc., the mechanical separator assures a uniform output regardless of the wear of the mill or variation of feed. With the addition of a mechanical separator, the operation of an open-circuit grinding becomes one of closed-circuit grinding, the mechanical separator assuming the entire responsibility for sizing the product. A circulating load is built up which may be increased to an amount several times greater than that of the open-circuit feed,

**Fig. 1.**

or until an analysis of the discharge to the separator shows only 70, 60, or even 50 per cent. of the desired fineness. The separator will pass only that portion of the material entering from the mill that meets the required fineness, automatically rejecting coarser particles, which are returned to the mill for further grinding. Thus the amount of material passing through the mill may be several times the amount formerly fed when operating with an open-circuit, but the material discharged from the separator is of uniformly controlled fineness. The capacity of the mill is increased, and the only additional power required is that necessary

to operate the separator, which is a very small percentage of the power required to operate the mill. The separator is so completely automatic that less labour is required, and where several mills and separators are installed it is often possible to reduce the number of operators.

When the separator is used grinding may be started with a coarser material than with open-circuit grinding. In handling certain materials this eliminates a preliminary sizing, and permits one unit to undertake both grinding and sizing. Another advantage is the cooling effect secured from the circulating load passing through the mill and the separator, as the heat generated in the mill is quickly dissipated by the volume and steady flow of material passing through the separator. This advantage is particularly useful when grinding cement clinker.

The chief advantages claimed for this separator are: 1, increase in output; 2, close control over uniformity of product; 3, ability to separate continuously with extreme fineness; 4, lower power consumption; 5, labour saving.

In operation, the product is fed through a hollow vertical shaft on to a distribution wheel or disc which has a tendency to throw the material over the edge and across the air space between the disc and the inner cone of the separator. At the same time a fan in the top of the separator is creating a large volume of circulating air which travels down between the inner and outer cones, entering the inner cone through the deflector doors. This large volume of air permits the picking up of all the dropping particles. The selection of the proper size material from these dropping particles is made by a patented arrangement which knocks out of the air current the over-size particles. By this means the amount of fine dust which would usually be discharged is reduced and separation is made more efficient. The separator is not dependent upon the speed of the air current to pick out the proper size particles.

The following reports describe the operation of these separators in cement factories. In one plant, two 14-ft. separators are used for classifying cement raw mix. The feed is a mixture of limestone ground to 46 per cent. passing a 200-mesh sieve together with tailings re-ground to 76 per cent. through a 200-mesh sieve. This mixture as fed averages about 60 per cent. passing a 200-mesh sieve, and the separators deliver a finished product at a uniform fineness of 93 per cent. passing a 200-mesh sieve. There is less than 0.5 per cent. variation in the fineness, and each separator produces 26 short tons per hour. In another cement plant a 16-ft. separator is operated in connection with six tube mills for clinker. Each mill produces an average of 29 barrels per hour, so that the total output of the separator is 174 barrels per hour. The fineness of the feed to the separator is from 74 per cent. to 76 per cent. passing a 200-mesh sieve, and the finished product from 96 per cent. to 97 per cent. through a 200-mesh sieve.

### Test Results.

Tests on the "Raymond" separators operating in cement works and elsewhere are giving the following results.

The 8-ft. separator operates on the following lines; 12 full-diameter blades; 12 "whizzers"; 350 revolutions per minute; vertical shaft; 15 h.p.:

| | Tons per Hour. | Per cent. Passing 35-mesh. | Per cent. Passing 65-mesh. | Per cent. Passing 100-mesh. |
|---|---|---|---|---|
| Feed .. .. | 5 | 95.8 | — | 86.3 |
| Fines .. .. | 4.8 | trace | 99.5 | 97.5 |
| Rejects .. .. | 0.2 | 44.5 | 16.8 | 9.5 |

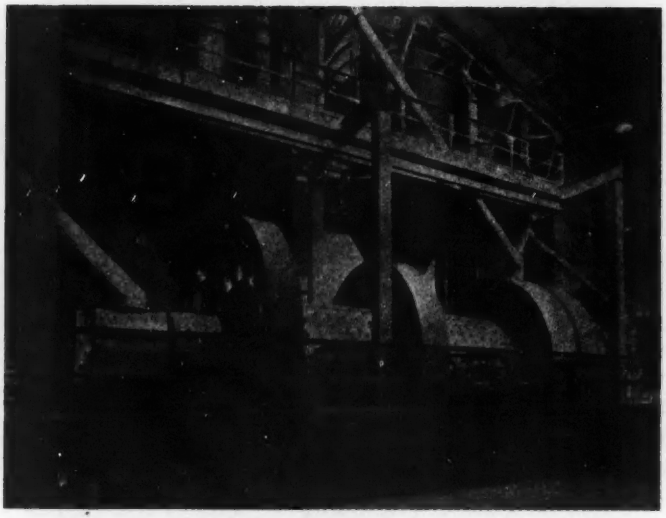

**Fig. 2.**

The 16-ft. separator operating on cement clinker has 35 "whizzers"; 12 fan blades; vertical shaft; 180 revolutions per minute; 58.5 h.p.:

| | Barrels per Hour. | Per cent. Passing 200-mesh* | Barrels per Hour. | Per cent. Passing 200-mesh† |
|---|---|---|---|---|
| Feed .. .. | — | 73 | — | 74 to 78 |
| Fines .. .. | 180 | 96 to 97 | 120 | 95.5 |
| Rejects .. .. | — | 40 to 45 | — | 36 to 45 |

Flour content, 49 to 50 per cent., 30 microns.

* 65 h.p. † 58.5 h.p.

The 14-ft. separator operating on cement raw mix has 24 " whizzers " ; 12 fan blades ; 200 r.p.m. ; vertical shaft ; 33 h.p. :

| | Tons per Hour. | Per cent. Passing 200-mesh. |
|---|---|---|
| Feed .. .. | 40.0 | 69.00 |
| Fines .. .. | 24.7 | 91.45 |
| Rejects .. .. | 15.3 | 34.50 |

8-ft. separator operating on cement has 12 fan blades ; 24 " whizzers " ; 257 r.p.m. ; vertical shaft ; 6 to 7 h.p. :

| | Lb. per Hour. | Per cent. Passing 300-mesh. |
|---|---|---|
| Feed .. .. | 2,068 | 83 |
| Fines .. .. | 1,880 | 98 |
| Rejects .. .. | 188 | 43 to 45 |

14-ft. separator operating on hydrated lime has 12 fan blades ; 7ft. 10in. diameter fan wheel ; 48 " whizzers " ; 225 r.p.m. ; 22 h.p. :

| | Tons per Hour. | Per cent. Passing 200-mesh. |
|---|---|---|
| Feed .. .. | 7.8 | 63.0 |
| Fines .. .. | 4.8 | 99.6 |
| Rejects .. .. | 3.0 | 19.0 |

Laboratory tests gave the following results on limestone with 94.35 per cent. passing a 100-mesh sieve, 84.4 per cent. passing a 200-mesh sieve, and 75 per cent. passing a 300-mesh sieve. Details of apparatus : 30-in. separator ; $2\frac{1}{2}$ h.p. motor ; speed on vertical shaft, 800 to 1,000 to 1,200 r.p.m. :

| | | 100-Mesh. | | 200-Mesh. | | 300-Mesh. | | Lb. per Hour. | |
|---|---|---|---|---|---|---|---|---|---|
| | r.p.m. | Fines. | Rejects. | Fines. | Rejects. | Fines. | Rejects. | Fines. | Rejects. |
| 24 " Whizzers " | 800 .. | trace | 97.66 | 99.98 | 78.31 | 99.9 | 61.2 | 184 | 616 |
| | 1,000 .. | 100 | 94.3 | 99.95 | 75.36 | 99.85 | 55.7 | 240 | 480 |
| | 1,200 | 100 | 92.45 | 99.9 | 65.5 | 99.76 | 33.86 | 330 | 375 |
| 12 " Whizzers " | 800 .. | trace | 94.36 | 99.62 | 84.4 | 96.04 | 75.0 | 400 | 440 |
| | 1,000 .. | 100 | 94.47 | 99.84 | 57.2 | 94.86 | 27.08 | 435 | 435 |
| | 1,200 .. | 100 | 79.66 | 99.3 | 43.38 | 93.68 | 18.86 | 630 | 270 |
| 6 " Whizzers " | 800 .. | trace | 92.6 | 96.21 | 20.4 | 87.2 | 9.84 | 640 | 220 |
| | 1,000 .. | 99.96 | 76.7 | 95.42 | 13.92 | 86.19 | 8.0 | 540 | 120 |
| | 1,200 .. | 99.97 | 62.8 | 97.59 | 14.28 | 87.73 | 7.88 | 780 | 180 |

The "Raymond" mechanical air separator is manufactured in Great Britain by Messrs. Mining and Industrial Equipment, Ltd., 11, Southampton Row, London.

Fig. 1 shows seven 14 ft. mechanical air separators separating cement raw mix. Each unit delivers 25 tons per hour of raw mix, taking it at a fineness of 69 per cent., passing a 200-mesh sieve, and delivering a finished product of which 91 per cent. passes through a 200-mesh sieve, with a variation in fineness of less than 0.5 per cent. Fig. 2 shows two 16 ft. separators operating in closed circuit with a three-compartment compeb mill for separating raw cement mix. The equipment has an output of 55 tons per hour, delivered at a fineness of 93 per cent., passing a 200-mesh sieve.


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